MindGarden

Grow Your AI-Generated VR Relaxation Forest with Brainwaves

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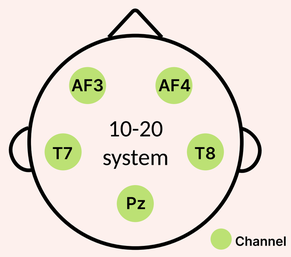
Abstract

In today's fast-paced world, managing daily stress and maintaining emotional wellness is a growing challenge. This project aims to develop an innovative system, called ***MindGarden***, that combines cutting-edge technologies—brain-computer interfaces (BCI), virtual reality (VR), and generative artificial intelligence (AI)—to revolutionize daily emotion regulation. MindGarden explores an ***interpretable and personalized pathway for BCI-VR emotion regulation*** by integrating arousal recognition with valence-oriented closed-loop control. ***Objective 1*** introduces an online arousal recognition scheme with a brainwave classifier pre-trained on database and subsequently fine-tuned for each individual, enabling reliable state tracking during VR therapy. ***Objective 2*** proposes a valence–driven closed loop and explore the personal calibration for enhancing emotion regulation. Together, MindGarden integrates arousal inference with valance-driven adaptation within a single framework, highlighting a interpretable protocol for personalized BCI–VR therapy. The system's effectiveness and user experience are comprehensively evaluated through user testing and iterative refinement. It represents ***a transformative approach to emotional well-being***, harnessing cutting-edge technological innovations to deliver accessible, personalized mental wellness solutions.

Introduction



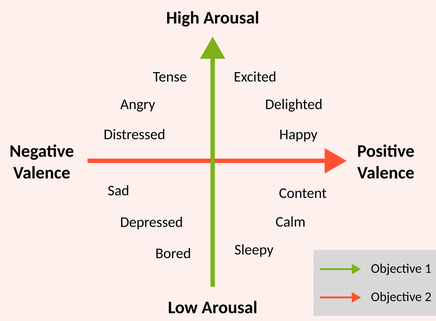
BCI Device: Emotiv Insight 5-Channel EEG Headset

In the field of human–computer interaction, virtual reality (VR) therapy is increasingly integrated with physiological computing, such as brain-computer interface (BCI), to facilitate emotion regulation [1-2]. Recent studies demonstrate both the feedback fidelity to genuine physiological signals and users' awareness of the feedback substantively modulate intervention outcomes and user experience [3-4]. Meanwhile, human emotions can be interpreted into a two-dimensional model: arousal and valence[5].

Within this context, we pursue the following two objectives in this project:

- ***Objective 1*** introduces a BCI-VR interaction scheme based on online recognition of users' arousal via a pre-trained, fine-tuned electroencephalogram (EEG) classifier;
- ***Objective 2*** proposes a users' valence-oriented BCI-VR loop and studies how personalized calibration enhances physiological regulation and user experience.

Together, we unify arousal recognition and valence-oriented loop within one VR therapy framework, using personalized calibration and rigorous controls to quantify efficacy and experience, toward an interpretable, reusable pathway for personalized BCI-VR interaction for emotion regulation.



Two-dimensional Model of Emotion

Brain-Computer Interface (BCI)

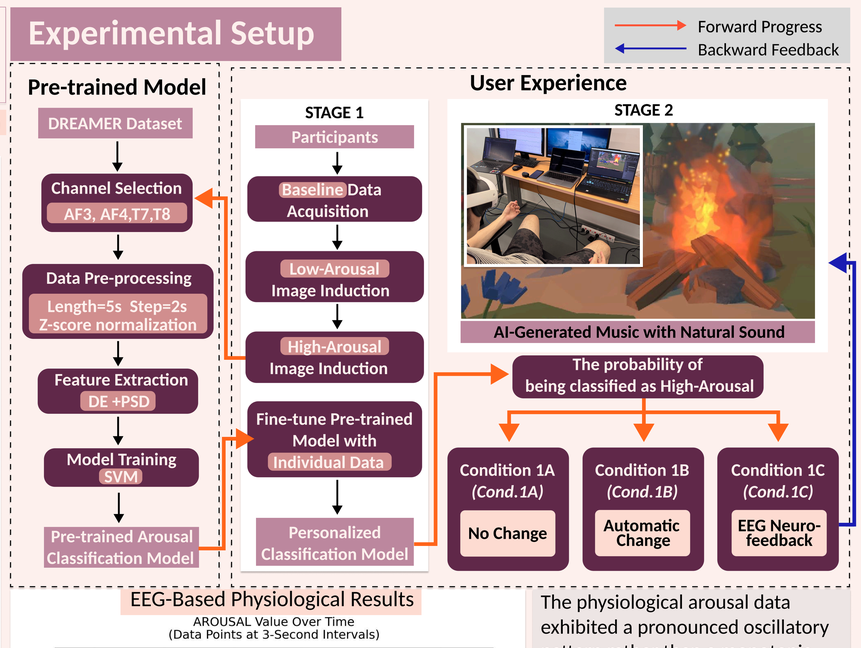
Objective 1

Aim

To design and evaluate a BCI–VR relaxation scheme utilizing a pre-trained and fine-tuned EEG classifier for arousal-based emotion recognition, and study the efficacy of dynamic neurofeedback, derived from EEG, in facilitating emotional regulation.

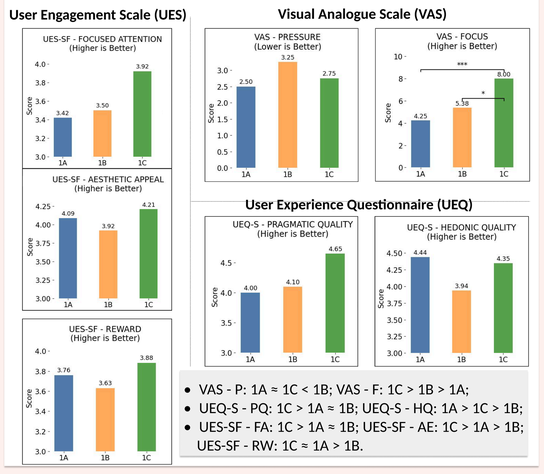
Participants: N = 10 (6 Males, 4 Females) Age: 20–30 years **Approved by the University Ethics Review Panel*

Experimental Setup



Results

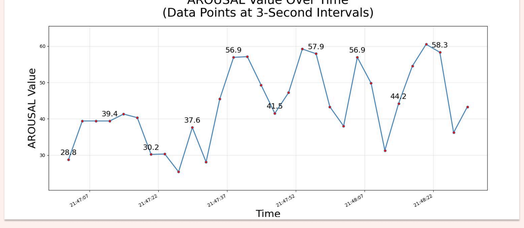
Subjective Questionnaire Results


User Engagement Scale (UES)
UES-SF - FOCUSED ATTENTION (Higher is Better)
UES-SF - AESTHETIC APPEAL (Higher is Better)
UES-SF - REWARD (Higher is Better)
Visual Analogue Scale (VAS)
VAS - PRESSURE (Lower is Better)
VAS - FOCUS (Higher is Better)
User Experience Questionnaire (UEQ)
UEQ-S - PRAGMATIC QUALITY (Higher is Better)
UEQ-S - HEDONIC QUALITY (Higher is Better)
Score
1A
1B
1C

- VAS - P: 1A ≈ 1C < 1B; VAS - F: 1C > 1B > 1A;
- UEQ-S - PQ: 1C > 1A ≈ 1B; UEQ-S - HQ: 1A > 1C > 1B;
- UES-SF - FA: 1C > 1A ≈ 1B; UES-SF - AE: 1C > 1A > 1B; UES-SF - RW: 1C ≈ 1A > 1B.

Cond.1C stands out as the superior all-rounder, demonstrating statistically significant advantages in Focus alongside strong performance in usability and reward. While *Cond.1A* excels in aesthetic appeal and shows the lowest stress levels, these differences did not reach statistical significance in the current sample.

EEG-Based Physiological Results



The physiological arousal data exhibited a pronounced oscillatory pattern rather than a monotonic trend. Throughout the session, arousal values fluctuated between approximately 28 and 60, with multiple marked peaks (e.g., 56.9, 57.9, 56.9, 58.3), indicating active regulatory processes during the intervention.

EEG neurofeedback (*Cond.1C*) emerges as the most effective intervention, enhancing focus, pragmatic quality, and arousal regulation. *Cond.1A* showed advantages in hedonic quality and stress reduction, while *Cond.1B* performed weakest overall. These results highlight the potential of neurofeedback to improve cognitive performance, with future designs needing to balance effectiveness and user enjoyment.

Objective 2

Aim

To develop and evaluate a valence-oriented BCI–VR closed-loop system to drive real-time feedback for relaxation, and investigate how individualized EEG β/α ratio (BAR) calibration improves physiological down-regulation and user experience (compared with a no-feedback control and guided breathing).

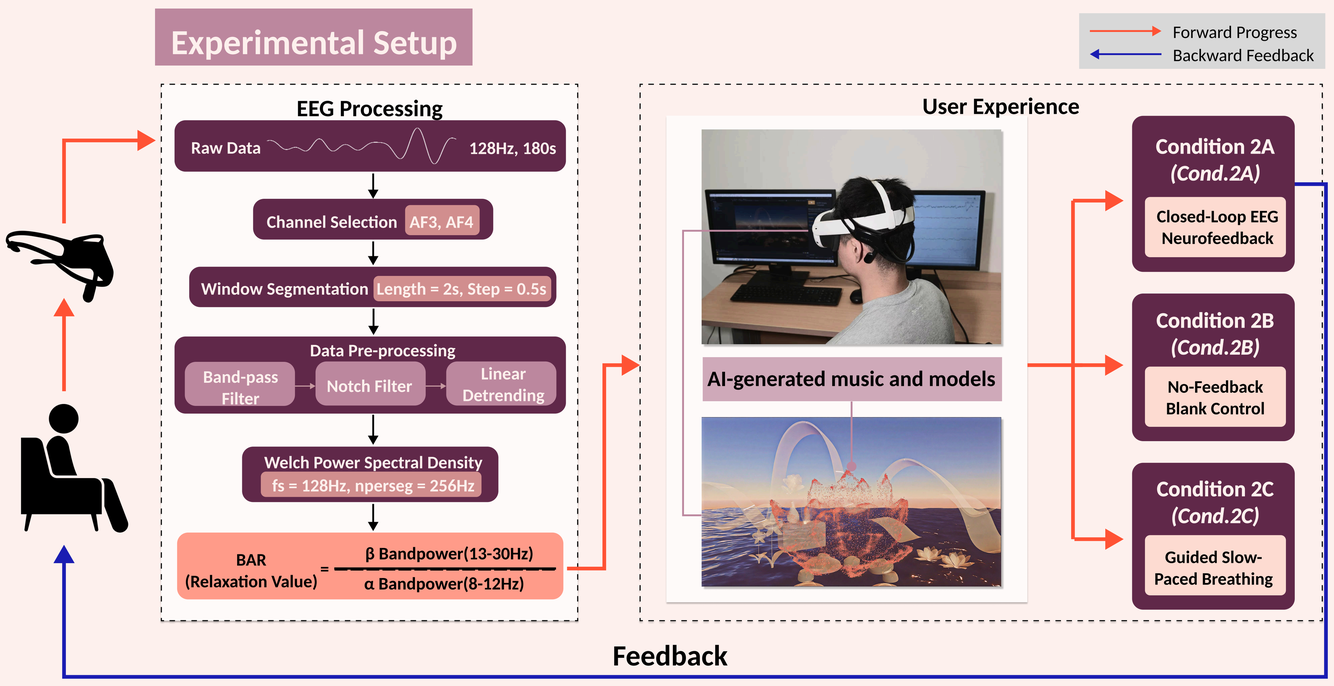
Participants:

N = 10 (6 Males, 4 Females)

Age: 20–23 years (M = 21.40, SD = 1.43)

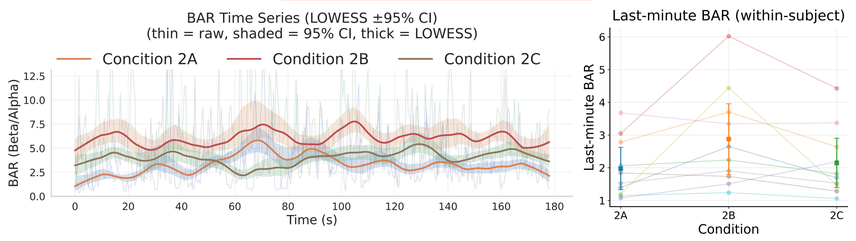
**Approved by the University Ethics Review Panel*

Experimental Setup



Results

EEG-Based Physiological Results

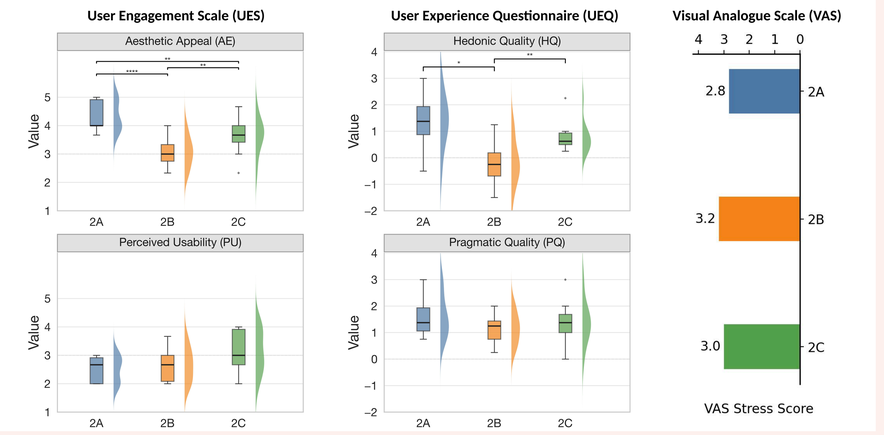


Top-left: BAR (β/α) time series with LOWESS; shaded bands denote ±95% CI. AUC over 180 s indexes cumulative arousal load (lower = more relaxed).
Top-right: Per-participant last-minute BAR (within-subject); lower = better end-state regulation.

AUC (mean ± SD): *Cond.2A* 368±179, *Cond.2B* 499±284, *Cond.2C* 374±173;
Last-minute BAR (mean ± SD): *Cond.2A* 1.98±0.90, *Cond.2B* 2.88±1.51, *Cond.2C* 2.15±1.05

Consistently, *Cond.2A* (closed-loop) and *Cond.2C* (paced breathing) showed lower last-minute BAR than *Cond.2B* (no-feedback), indicating better relaxation. AUC displayed a quadratic trend (2B highest; 2A≈2C lower); despite non-significant pairwise tests, $\eta^2_p \approx .34$ supports 2A≈2C outperforming 2B on relaxation.

Subjective Questionnaire Results



- UES-SF — AE: 2A > 2C > 2B; PU: 2A ≈ 2C; UEQ-S — HQ: 2A ≈ 2C > 2B; PQ: 2A ≈ 2C; VAS : 2A < 2B < 2C

Closed-loop feedback *(Cond.2A)* confers a clear aesthetic advantage over *Cond.2B* (and generally over *Cond.2C*) without degrading usability; perceived stress is lowest in *Cond.2A*, though differences are not significant with the current sample.

Conclusion

MindGarden integrates online ***arousal recognition (Objective 1)*** with ***valence-oriented closed-loop control (Objective 2)*** within ***a single interpretable BCI-VR framework***. Objective 1 utilizes an EEG classifier that is pre-trained on database and fine-tuned for each individual, facilitating robust in-session state tracking during therapy. Objective 2 employs the β/α ratio (BAR) as an interpretable control signal, exhibiting a consistent relaxation pattern when compared to no-feedback and guided slow-breathing baselines. Both conditions result in a reduction of BAR compared with the no-feedback condition, with the closed-loop condition yielding the most favorable aesthetic experience and the lowest perceived stress under the present sample, timing, and controls. Taken together, the system unites interpretability, personalized calibration, and rigorous baselines, establishing ***a reusable and practice-ready pathway for personalized BCI-VR emotion regulation***.

Future Work

- ***External Validity:*** Enhancing external validity by diversifying participant demographics and contexts, and employing randomization along with cross-context validation.
- ***Multimodal Physiology:*** Integrating heart rate variability (HRV), galvanic skin response (GSR), and respiration data for data fusion and cross-validation.
- ***Cross-Device/Channel Consistency:*** Evaluating consistency across head-mounted displays and higher-density EEG systems, while refining personalized calibration methods.

References

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